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Optimization under uncertainty of a composite fabrication process using a deterministic one-stage approach

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Abstract

Process design under uncertainty has received considerable attention in recent years, and has led to the development of several modeling and solution approaches. These approaches are broadly categorized under stochastic formulations (model parameters with probability distributions), multiperiod formulations (where uncertain parameters are discretized into a number of deterministic realizations), and parametric programming formulations. This paper presents an application of the one-stage optimization problem (OSOP), a multiperiod method, to find optimal cure temperature cycle design under uncertainty for polymer-matrix composites fabrication using the pultrusion process. The process is governed by a highly non-linear system of partial differential-algebraic equations.

The OSOP method is also systematically compared with a sampling-based approach in terms of computational efficiency and solution quality. Most work done so far using such deterministic methods has focused on problems where the performance objective function (often cost) and process constraints are analytic/algebraic in nature. In contrast, in materials processing simulations, evaluation of the objective function and the process constraints are based on the solution of differential-algebraic equations (DAE).

Keywords: Optimization; Uncertainty; Pultrusion; OSOP; Sampling

1. Introduction

Chemical process design under uncertainty has received a great deal of attention in the past two decades. Solution approaches dealing with such process simulations under parametric uncertainty fall under three main categories; namely (i) stochastic, (ii) deterministic, and (iii) parametric programming. Stochastic methods model uncertain parameters using probability distributions (Chaudhuri & Diwekar, 1996; Mawardi & Pitchumani, 2004; Padmanabhan & Pitchumani, 1999a,b; Pai & Hughes, 1987; Pistikopoulos & Ierapetritou, 1995; Pistikopoulos & Mazzuchi, 1990; Straub & Grossmann, 1993). Here, the process is simulated at a large but fixed number of points (sample size) within the domain of uncertain variables represented by various probability distributions. The number of samples chosen for the stochastic simulations is usually on the order of hundreds to thousands, and is determined via convergence analysis (Mawardi & Pitchumani, 2004; Padmanabhan & Pitchumani, 1999a), which clearly requires large computational effort. On the other hand, deterministic methods, such as the one-stage optimization model, tend to employ an adaptive sampling strategy in which the number of points (sample size) is systematically increased. Here, the uncertain parameters are discretized into a number of finite values, which are then used in the "multiperiod" optimization problem (Grossmann & Sargent, 1978; Halemane & Grossmann, 1983; Varvarezos, Grossmann, & Biegler, 1992). A third approach for solving design problems under uncertainty involves using parametric or sensitivity programming techniques (Acevedo & Pistikopoulos, 1996; Takamatsu, Hashomoto, & Ohno, 1970; Varvarezos, Grossmann, & Biegler, 1995). Other approaches using combinations of the above three methods are also reported in the literature (Ierapetritou, Acevedo, & Pistikopoulos, 1996).

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